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Review Article

A review on the impact of energy drink consumption on heart rate and blood pressure in healthy individuals

Nur Qistina Balqis Mohd Azuan Goo [1], Puteri Sofea Qurratu'ain Mohd Sofian [1*], Nur Farha Liyana Izuddin [1]

1 Faculty of Pharmacy, Universiti Sultan Zainal Abidin, Besut , Terengganu, Malaysia

***Corresponding author:** psofeaa246@gmail.com

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Abstract:

This systematic review evaluated the impact of energy drinks (EDs) consumption on heart rate and blood pressure in healthy individuals. The prevalence of EDs ingestion has substantially increased across the population both locally and worldwide, thus the various studies of the haemodynamic effects, mainly blood pressure (BP) and heart rate (HR). Multiple components of EDs include caffeine, natural and artificial sugars, taurine, herbals and other, were proven as contributors to the effects said, in accord to the literatures. This coherent review aims to gather the recent evidence from the year of 2018 up until 2025, on the short-term effects of EDs towards the haemodynamic and physiological responses, namely SBP, DBP and HR. It is done to highlight the consistency across the findings made previously and to reveal the grounds of differences that exists. Studies published in between 2018 until 2025 were collected from diverse databases, of including PubMed, Web of science, Scopus and many others. The studies comprise of either randomized, crossover or observational outcomes on cardiovascular system upon intake of EDs. Data of BP, HR, other related cardiovascular parameters, sample characteristics, EDs contents were observed, Cardiovascular effects from EDs consumption may differ across populations according to its formulations.

Keywords: Blood Pressure; Caffeine; Cardiovascular System; Diastole; Energy Drinks; Healthy Volunteers; Heart Rate; Hemodynamics.

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Introduction

Energy drinks (ED) are beverages that are contented of multiple ingredients, most commonly caffeine, taurine, sugar, artificial sweeteners and other herbal stimulants. It is widely advertised with the claims of increasing the stamina, focus, cognition and wakefulness in individuals [1]. Rapidly gaining the popularity, EDs consumption prevalence have been remarked substantial and successfully appealed consumers of all ages. This extensive ingestion however may grow some concern, although generally considered safe when consumed, as high doses of stimulants and rapid intake may exert unwanted stress on the cardiovascular system, as recently reported by Ramcharan et al [2], an incidence of cardiac arrest.

Caffeine, a methylxanthine is a standard ingredient usually incorporated in EDs, ranging about 70 to 200mg per 16 fl oz Caffeine can produce an elevation in blood pressure as an adenosine receptor antagonist, that activate the innervation of sympathetic nervous system through the increasing release of excitatory neurotransmitters [3]. This stimulation causes vasoconstriction and increases in peripheral vascular resistance, hence the rise in both SBP and DBP upon intake. When combined with taurine, sugars or other stimulants, these effects are rather more pronounced.

The acute cardiovascular responses to energy drink consumption have been extensively evaluated across diverse age groups and physiological conditions [4]. Single weight adjusted doses of energy beverages in children and adolescents significantly alter ambulatory blood pressure measurements [4]. High volume consumption of these formulations prolongs electrocardiographic parameters such as the QTc interval and elevates systolic blood pressure from baseline [5]. Furthermore, short term ingestion produces distinct sex specific hemodynamic patterns, increasing diastolic blood pressure and heart rate in males while elevating systolic blood pressure in females [6].

Brand specific differences in energy drink compositions also contribute to distinct systolic and diastolic responses [7]. In addition to blood pressure variations, energy drinks can impair endothelial function as measured by flow mediated dilatation [8]. Acute ingestion alters measures of arterial stiffness [9]. Finally, both novel noncaloric formulations and traditional sugar sweetened energy drinks significantly elevate resting systolic blood pressure, an effect that remains heightened following exercise testing [10].

Over the last decade, expansion of deep and thorough research on both clinical and scientific perceptions have been discussed, including EDs effects on haemodynamic measurements and autonomic functions. Focuses were predominantly blood pressure (BP), heart rate (HR), electrocardiographic parameters and other physiological responses, that collectively suggests turning down the uptake of EDs, specifically individuals with pre-existing cardiovascular risk. Numerous controlled trials have shown the rises of BP and HR within an hour of ingestion, and some presented prolongation of QTc and other findings.

In this following review, several recent studies are collected to rule out the significance of intake of EDs in multiple groups of healthy individuals through measurable cardiovascular changes. This aims to highlight the consistencies and maintain the discrepancies between all these literatures and determine the underlying factors that may contribute to the variations of haemodynamic responses among different populations.

Methodology

Search strategy

This systematic review was carried out in reputable scientific databases, such as Web of science, Scopus and PubMed. The keywords used for searching were “energy drinks”, “blood pressure”, “heart rate” and “healthy individuals”.

Inclusion criteria

This systematic review studies included precise focuses such as:

- Healthy participants of any age, sex, weight, height, body mass index, fitness level
- Blood pressure reading (diastolic and systolic)
- Heart rate
- Energy drinks consumption

Exclusion criteria

This systematic review excluded such focuses as:

- Participants diagnosed with medical or health conditions (e.g, cardiovascular, hypertension)
- Abstract-only studies, case reports, observational studies, review studies and unpublished studies.

Synthesis of review

The collected data from various studies were observed, in accordance with PRISMA criteria, the impact of energy drinks on blood pressure and heart rate.

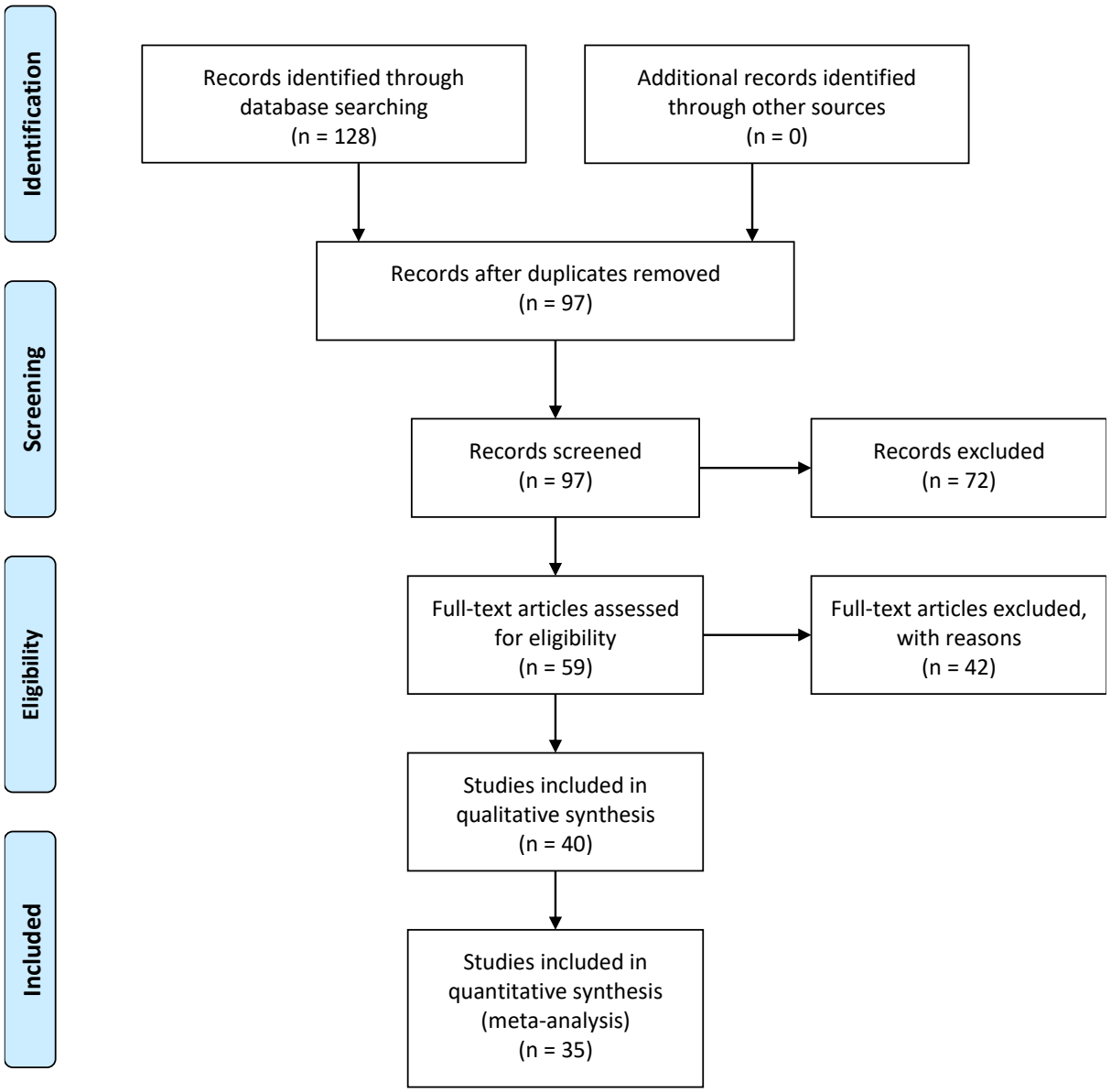

Figure 1. Preferred Reporting Items for Systematic Reviews (PRISMA) 2009 flow chart for gathering data once appropriate studies have been found. A total of 128 studies were found by entering the desired criteria into different databases. 31 of these published articles were found to meet the inclusion criteria for the current systematic review after the evaluation.

Findings and Discussion

Paediatric and Adolescent Hemodynamic Responses

In paediatric populations, bodyweight adjusted ED consumption significantly alters cardiovascular parameters and raises blood pressure [4]. High volume ED ingestion similarly causes acute increases in systolic blood pressure (SBP) alongside QTc interval prolongation [5]. Sex specific hemodynamic variations have been observed in collegiate athletes, where ED consumption produces significant post ingestion increases in SBP among females and diastolic blood pressure (DBP) among males [6]. Comparisons of diverse commercial ED formulations in young adults demonstrate brand dependent SBP elevations within 20 minutes [7]. Furthermore, acute ingestion of Monster Energy Drink impairs endothelial function and significantly alters SBP, DBP, and heart rate [8]. Arterial stiffness and hemodynamic evaluations indicate that standalone ED administration significantly modifies DBP metrics [9].

Impact of Ingredient Profiles and Athletic Status

Comparing noncaloric ED formulations with traditional sugar sweetened beverages demonstrates that both significantly elevate resting SBP, with post exercise SBP increases being particularly pronounced under noncaloric conditions [10]. Athletic background also influences hemodynamic outcomes, as central and peripheral SBP increases post consumption are marked in sedentary and physically active individuals, whereas trained bodybuilders show muted responses [11]. When comparing commercial EDs directly against coffee at equivalent caffeine doses, ED consumption induces significant increases in both peripheral and central SBP [12].

Dosage Variations, Acute Effects, and Gender Differences

In contrast to acute trials, chronic high volume ED consumption in adolescent populations does not show statistically significant differences in resting blood pressure or heart rate compared to non consumers after rigorous statistical adjustments [13]. However, acute sequential hourly ED ingestion leads to an 8% increase in DBP [14]. In young adults, single dose ED intake yields modest SBP increases that achieve statistical significance primarily in female subgroups [15]. When combined with exercise stress, ED consumption produces marked additive increases in resting and exercise SBP and DBP [16]. Conversely, single can Red Bull administration in young females results in heart rate deceleration without significant alterations in resting SBP or DBP [17].

Vascular Function and Ambulatory Monitoring

Linear mixed effects modeling indicates that complex ED matrices containing caffeine and taurine differentially alter blood pressure compared to sports drinks alone [18]. Specialized SphygmoCor central arterial assessments confirm that ED consumption yields significantly greater peripheral SBP, peripheral DBP, central SBP, and central DBP increases compared to placebo [19]. Post consumption flow mediated dilation testing at 90 minutes demonstrates significant increases in heart rate, SBP, and DBP [20]. In contrast, crossover trials evaluating heart rate variability during aerobic exercise recovery demonstrate no significant differences between ED and water control conditions [21]. Short term single can ingestion in healthy volunteers similarly shows no statistically significant 60 minute changes in echocardiographic parameters, SBP, or DBP [22].

Long-Term Exposure and Exercise Interventions

In paediatric populations, weight adjusted caffeine intake leads to lower median heart rate and QT RR interval shifts [23]. Furthermore, 24 hour ambulatory monitoring in children confirms that single dose ED exposure yields significantly elevated 24 hour SBP and DBP compared to placebo [24]. Comparative evaluations of liquid versus powder dissolvable commercial stimulants reveal increased SBP and DBP values across both formats without affecting pulse rate [25]. Volume dependent parallel trials show that both 250 mL and 500 mL ED doses lead to significant increases in heart rate, SBP, and DBP over a two hour observation period [26].

Cross sectional survey data confirm that frequent ED consumers experience significantly higher rates of elevated blood pressure, chest discomfort, and palpitations [27]. Longitudinal prospective testing demonstrates that consuming two cans daily over 28 days causes significant long term increases in blood pressure, heart rate, QTc interval, and fasting blood glucose [28]. Short term intake prior to athletic fitness tests significantly increases baseline heart rate and blood pressure [29]. When compared against fruit juice alternatives, ED consumption uniquely raises DBP and blood glucose levels [30]. During sport specific exercise, pre workout caffeine ingestion significantly elevates heart rate during basketball performance drills [31]. Pre exercise Red Bull consumption similarly enhances short term maximal performance while elevating pre and post exercise blood pressure and glucose [32]. Finally, ingredient isolated trials demonstrate that caffeine alone or combined with taurine drives heart rate and SBP increases, whereas taurine alone produces no significant cardiovascular changes [33].

Details regarding the study designs, participant characteristics, interventions, statistical tools, and primary outcomes are summarized in Table 1.

Table1: Summary of included studies evaluating the impact of energy drink consumption on cardiovascular parameters

Studies	Interventions	Participations	Study Design	Statistical Tools	Outcomes
Oberhoffer et. al, 2022 [4]	weight-adjusted amount of an ED (3mg caffeine per kg of body weight) or placebo containing a similar amount of sugar but without conventional ED ingredients	healthy children and teenagers of mean age 14.53 years n = 27required not to consume any sources of caffeine or drugs 48 h before and 24 h after study participation. overnight fast (with allowance for water) was asked preceding every study day. not to consume any food or liquids during each day's study durati	randomized, single-blind, placebo-controlled, crossover clinical trialpersonal interview, clinical examination, conventional echocardiography, 24-h Holter ECG and 24-h blood pressure measurement	SBP, DBP, HR: two-way repeated-measures ANOVA;distribution: Ln or Sqrt data;post-hoc testing: The Bonferroni adjusted pairwise test;maximum change from baseline: paired t-test	mean SBP increased up to 5.23 mmHg; mean DBPup to 3.29 mmHg; HR lower after ED intake
Shah et. al, 2019 [5]	32 oz of either energy drink A, energy drink B, or placebo within 60 minutes on 3 study days with a 6-day washout period in between	healthy volunteers between the ages of 18 and 40 years, mean age 22.1 n = 34avoid ingestion of caffeine and energy drinks for 48 hours before each study day	randomized, double-masked, placebo-controlled, crossover clinical trialmeasured at baseline and at 30, 60, 90, 120, 150, 180, 210, and 240 minutes on each study day	repeated-measures analysis of variance, with a post hoc Tukey Honestly Significant Difference (HSD)baseline-adjusted, placebo-corrected changes between drink A and drink B compared: paired t test	prolongs the QTc interval;SBP: significantly higher from baseline at all time points for both drink A and B ($p \leq 0.027$);Fridericia's corrected SBP & DBP, also significant ($p = <0.001$);
Rabuya et. al, 2025 [6]	330 ml of energydrink, completed a washout period, and then performed a post-test	collegiateathletes (12 males, 9 females), age of 17-20 (mean = 18.14)n = 21abstained from consuming energydrinks, caffeinated beverages, and other stimulants for three days before the pretest, also throughout washout periodmaintain a minimum of eight hours of sleep per night	pretest-washout-posttest design, pretest:remained seated for 50minutes before testing to standardize their resting physiological state. BP and HRwere continuously monitored and recorded every five minutesposttest:ingesting an energy drink 50 minutes before testing, then measured as the pretest normality: Shapiro-Wilk test;pre–and post-test differences: paired sample t-tests	IBM SPSS Statistics version 29normality: Shapiro-Wilk test;pre–and post-test differences: paired sample t-tests	in males, the significant increase in DBP ($p = 0.040$) and HR ($p = 0.029$)in females, increase in SBP ($p = 0.032$)
Nagy et. al, 2019 [7]	consumed 250 mL drink (three types of energy drink and one control drink) on	nine normal BMI, one overweight,meanage of 21.4 yearsn = 10not to consume	cross-sectional study, questionnaire, measurements were	paired t-testand chi-square test by Past3 and SPSS (Version 22)	drink 2 shows significant increase in SBP ($p < 0.05$)no significant

	experimental days	any caffeine-containing drinks for 12 hrs before the study	performed before consuming and 20 min after consuming the drinks, on the arm of the non-dominant hand and were repeated three times.		changes in DBP and HR for all three drinks
Higgins et. al, 2020 [8]	24 oz Monster Energy Drink®	healthy non-smoking young volunteer medical students, average age of 24.7 years (range 23–27 yearsn = 44not allowed to eat, drink, or move about during post-consumption	baseline testing of endothelial function using the technique of endothelium-dependent flow-mediated dilatation (FMD), tested, and measurement repeated 90 minutes later	Microsoft Excel;discrete variables analysis: Student's t test for unpaired samples. A two-sided $p < 0.05$ electrocardiogram variables to compare significance at baseline and 90 min post-consumption: ANOVA testing	15-mins post-consumption:SBP: $p < 0.05$;DBP: $p < 0.05$;HR: $p < 0.05$;90-mins post-consumption:SBP: $p = 0.36$;DBP: $p = 0.02$;HR: $p < 0.05$;
Yasar et. al, 2025 [9]	250 mL of a commercially available energy drink	n = 64participants were told to avoid caffeinated products such as tea, chocolate, or cola drinks, and alcohol for at least 48 hours prior to the study date and on the day of the study	cross-sectional study, baseline measurement was obtained while the subject sitting after a minimum rest of 5 minutes. upon consumption, measurements were repeated 30 minutes, and 2 hours after energy drink consumptionall were performed in the morning after a light breakfast between 08:00 and 09:00 AM, in a quiet, temperature-controlled room at 20-23°C	SPSS Version 25 normality: The Kolmogorov-Smirnov test differences between variables before and after energy drink consumption: repeated measure analysis Categorical variables: Fisher's exact test. correlations of indices of arterial stiffness with the different variables studied: Pearson or Spearman correlation coefficientstatistical significance as 2-sided P value of <.05.	SBP: $p = 0.973$; DBP significant changes; $p = 0.011$;HR: $p = 0.513$
Banks et. al, 2024 [10]	three types of ED, of 16 oz, non-caloric energy drink, containing novel ingredient blend including caffeine (C4 energy drink, C4E) or traditional sugar-containing energy drink, included caffeine and	healthy, physically active males aged 20–35 years (mean 25 ± 4 y), exercises at least 3 days per week, not been consuming more than 21 servings of caffeine per week, BMI of 18.5–34.9 kg/m2completed three	randomized, double-blind, placebo-controlled, crossover trialurine sample analyzed for urine-specific gravity, commence only if value between 1.005-1.030consumption of drink under 5 minuteslaid down on	corrected using the Greenhouse–Geisser correctionindependent, one-way repeated measures ANOVAsrepeated measures mixed-effects models were used to	both C4E and MED significantly affect SBP at rest ($p < 0.001$)post-GXT SBP, C4E shows significant increase ($p < 0.001$)HR is higher with MED ($p = 0.035$), and C4E ($p = 0.010$

	sugar (Monster energy drink, MED) and placebo	experimental visits under semi-fasted conditions (5-10h)n = 30abstained from exercise, caffeine, and alcohol for 24 h	a padded examination table in a semi-recumbent position and rested quietly for 10 min, then measurements of LBF and ECG, resting BP and oxygen saturation were takenmeasurements once again taken 40-mins post-consumptionperformed other several tests (graded exercise test (GXT), fatigue test)blood pressure, oxygen saturation, ECG were recorded for the final time	analyze changesGraphPad Prism	
Parl et. al, 2023 [11]	given 1 min to drink 473 mL of Monster Energy	young men of mean 30.0 ± 3.9 yearstotal participants divided equally into three different groups of reported physical activity; 15 sedentary [CON](no participation in regular physical activity); 15 physically active [PA] (≥3 h/week of aerobic and/or resistance exercise); 15 bodybuilders [BD] (exercising for at least 5 years and participating in competitions before the study)n = 45refrained from food, caffeine and smoking for at least 8 h before	cross-sectional and quasi-experimentalrested quietly in a supine position for 20 min. steady-state hemodynamic data as the pre-consumption baseline were obtained for 5 min, and the carotid-femoral pulse wave velocity (cfPWV) and flow-mediated dilation (FMD) were determined. in a semi-recumbent position and given 1 min to drink 473 mL of Monster Energy then returned to the supine position to measure hemodynamics at the time points of post, 30- and 60-minutes post-consumption	normality: Kolmogorov-Smirnov test effects of ED on dependent variables: Two-way ANOVA; Tukey method post-hoc test if significant interactioncompare time points post-consumption: One-way ANOVA SPSS version 28.0	central and peripheral blood pressure markedly increased in the PA and CON groups ($p < 0.05$) but not in the BD group
Schüttler et. al, 2022 [12]	240 mg of caffeine in two independent experiments, either by consumption of coffee or an energy drink	mean age 31.1n = 23regular but not excessive coffee drinkers (coffee intake was 1–2 cups/day on average) and only occasional consumers of energy drinks	cross-over interventional pilot studyfirst session: 750 mL of a commercial energy drink (containing 32 mg caffeine/100 mL (0.03%), 0.4% taurine, 11 g/100 mL sugar)second: three cups	GraphPad software Prism 9P values were calculated by paired sample Wilcoxon testscorrected for multiple comparisons using the Holm–Sidak	significant changes pBP systolic ($p = 0.013$) and cBP systolic ($p = 0.017$)

			(40 mL/cup) of coffee (containing 80 mg caffeine/cup)both were consumed within 15 mins, at intervals of 48h, and to avoid other caffeine sources 48hr before each sessionHR, BP and PWV collected with a BR-102 plus pulse wave analyzer, baseline and 45-mins post-consumption		
Menzel et. al, 2025 [13]	No researcher-administered intervention, naturally occurring chronic high ED consumption (≥4 days/weeks for past 12 months, >3 mg caffeine from EDs/kg BW/day)	Adolescents in Berlin, age of 15-18 years (mean = 16.0), chronic high EDs consumer, n=97, in comparison with control groups, n = 160.	Cross-sectional study in two phases: Phase one – online questionnaire to assess data about consumptions of EDs and lifestyle, Phase two – cardiological examination	Analyses conducted using SAS software, version 9.4, p-value < 0.05. However, Bonferroni correction was applied, thus p-value < 0.0002.	No statistically significant differences in HR, BP, and cardiological parameters between chronic high EDs consumer groups and control groups.
Nowak et. al, 2018 [14]	Each participant consumed three portions of EDs with 250 mL (750 mL in total), at one-hour intervals. Conversely, the control groups drink 250 mL of spring water (750 mL in total), also at one-hour intervals. Blood pressure and heart rate of each participant were measured for seven times.	68 volunteers of heathy adults, 78% is female students. Mean age \approx 25 years)	Randomizedcontrolled acute intervention study. Healthy young adults were randomly assigned to consume either energy drinks or water. Measurements were taken before and after consumption	Results were analysed by calculating the mean and standard deviation. The result was interpreted using MS Excel 2010 Analysis ToolPak software (Microsoft,Redmond, WA, USA), with one-way analysis of variance (ANOVA) and pre- and post-intervention values compared using Turkey's test. P-value < 0.005.	No significant effect on SBP (p = 0.809), while there is a significant increase by 8% for DBP (p = 0.003). There is no significant changes in HR also (p= 0.750).
Patil et. al, 2019 [15]	Participants consumed in pace 4 min, 355 mL of degassed energy drink, which contain, caffeine (114 mg), taurine (1420 mg), glucuronolactone (84.2 mg), sucrose and glucose (39.1 g) at room temperature. BP and pulse rate recorded after one-	40 healthy MBBS students studying in Bangalore Medical College and Research Institute in the age group of 19 to 22 years	Interventional,single-group pretest–posttest (before-and-after) study.	Descriptive statistics (Mean ± SD) and Student's paired t-test (two-tailed). Significance set at p ≤ 0.05.	Heart rate is significantly increase after one-hour post consumption (p = 0.05), SBP increased by 3mmHg (p = 0.23, not significant), and DBP increased by 2mmHg (p = 0.52, not significant).However, in female subgroups, SBP

	hour post-drink.				increased significantly by 5mmHg (p = 0.05).
Kozik et. al, 2018 [16]	Consumption of two cans (16 oz) energy drink in healthy young adults, followed by exercise (a standardized exercise session)	23 participants (28 ± 6.9 years old, with 13 males)	Acute, open-label, single-group (no placebo mentioned) observational/experimental study measuring baseline and post-intervention responses over time (pre-post with exercise challenge	The statistical software R version 3.4.0 (R Foundation for Statistical Computing, Vienna, Austria) was used for all of analyses	A statistically significant increase in systolic BP was observed in the PC period both while resting (baseline = 122 ± 12.7 mm Hg; PC = 132 ± 16.8 mm Hg; p ≤ 0.001) and during exercise PC (baseline = 136 ± 14.0 mm Hg; PC = 153 ± 14.6 mm Hg; p ≤ 0.001. A statistically significant increase in diastolic BP during rest PC (baseline = 76, ±8.3 mm Hg; PC = 81 ± 11.5 mm Hg; p = 0.009) as well as during exercise PC (baseline = 78 ± 9.5 mm Hg; PC = 88 ± 11.5 mm Hg; p ≤0.001). The heart rate also increased during rest PC and exercise PC.
Costa et. al, 2023 [17]	Single oral ingestion of 250 mL Redbull® (standard can). Blood pressure and heart rate were measured at baseline, 30 min and 60 min post-consumption	30 healthy young female adults netween the age of 18-22 years old. Mean age = 19.96 ± 1.13 years	Non-randomized pre-post intervention study.	Categorical variables describe by frequency and percentage while continuous variables by mean and SD. ANOVA test for repeated samples was used to evaluate the behaviour of continuous variables with normal distribution in the 3 collection phases. P-value < 0.05 is considered significant. Statistical analysis was performed by using software IBM SPSS® v.27 (National Opinion Research Center, Chicago, Ill, USA) and GraphPad	There was significant decrease in heart rate (p < 0.001), no significant change in SBP (p = 0.644) and DBP (p = 0.162).

				Prism v. 6.04 (La Jolla, San Diego, Calif, USA).	
Basrai et. al, 2019 [18]	Commercial ED, Redbull®, administered as repeated 250 mL portions (participants drank 250 mL within 15 min; total product administration required 45–60 min depending on volume). Tested volumes: 750 mL (G750) or 1000 mL (G1000). Also tested: CP (control sports drink) and CP + added components (CP + C [caffeine], CP + T [taurine], CP + G [glucuronolactone], CP + C + T).	n = 38 healthy young adults (19 M, 19 F), mean age ≈ 22.3 ± 1.8 y, BMI ≈ 23.0 ± 1.7 kg/m^2; no relevant medical history.	Randomized, doubled-blind, controlled trial performed in parallel and crossover manner	Linear mixed-effects models (nested series) fitted for each outcome (random subject effect; fixed effects for study product, volume, treatment order). Log-transformations applied where using Shapiro-Wilk test and QQ normality plots, needed (HR, glucose, insulin, HOMA-IR, K). Model checked for ordering effects; final estimates reported as difference from baseline and difference from CP. Software: IBM SPSS v21 and R v3.5.0 (lme4, lmerTest). P < 0.05 deemed significant. No correction for multiple testing.	After1h, administration of an ED caused an increase in systolic BP (116.9± 10.4 to120.7± 10.7mmHg, mean± SD, P < 0.01). EDs increase hear rate (p < 0.01). CP + C also increasedboth systolic and diastolic BP (P < 0.001 and P < 0.01, respectively), whereas CP + C + T only increased diastolic BP (P < 0.05)
Lee et. al, 2019 [19]	Each participants drink 24 oz of ED and 24 oz cherry and lime flavoured carbonated placebo drink on two separate days. Participants were ask to refrain from any caffeine, alcohol, and ED consumption for at least 48 hours and fasting overnight with no food or drinks except 10 hours before study visit. During the visit BP and HR are measured.	20 participants with mean age = 22.55 ± 5.37	The study design is a randomized, controlled, double-blind, crossover clinical trial.	Baseline characteristics and endpoints were reported using descriptive statistics; percentage for discrete variables and mean with standard deviation for continuous variables. Shapiro-Wilk test was used to determine normal distribution of the data given small sample size. Wilcoxon test was used to detect statistical difference for electrocardiogram and SphygmoCor endpoints while Chi-square test was	Maximum baseline-adjusted peripheral SBP increase: ED 11.10 ± 5.24 mmHg vs placebo 6.08 ± 7.07 mmHg, p = 0.006. Peripheral DBP (mean difference = 2.95 ± 6.02 mmHg, p-value=0.033), central SBP (mean difference = 4.17 ± 9.08 mmHg, p-value = 0.037), and central DBP (mean difference = 2.92 ± 5.86 mmHg, p-value = 0.021) were found to be greater in energy drink arm. HR is similar between arms.

				used for adverse events. Mann-Whitney U test was used to determine any effect of randomization and duration of drinking on outcomes. Data collection and analysis were performed with Microsoft Excel (Version 16.10, Microsoft, Redmond, WA) and SPSS Version 25	
Bendary et. al, 2024 [20]	Single commercially available Red Bull energy drink consumed within 20 minutes. Protocol timing: hemodynamic & FMD measured at baseline and 90 minutes after consumption. Article text contains two size mentions; the protocol states 355 mL Red Bull (reported contents: ~284 mg taurine, 53.25 mg caffeine, 39 mg sugar).	n = 50 healthy young adults, mean age 24.02 ± 2.69 years (20–30); 28 males (56%), 22 females (44%); BMI mean 22.24 ± 1.95 kg/m^2 (inclusion: age 20–30, BMI 19–25, non-smokers, no regular ED users).	Observational within-subject (pre–post) study (healthy volunteers measured at baseline and 90 min after ED). n = 50	continuous data: Student t-test (paired comparisons); Categorical: Chi-square; linear regression used for FMD delta vs gender; significance level α = 0.05. Software: SPSS	Heart rate:Post-ED (90 min) mean 74.10 bpm. Statistical test: paired t; p = 0.002SBP:Post-ED (90 min) mean 118.00 mmHg. Paired t; p < 0.0001DBP:Post-ED (90 min) mean 78.80 mmHg. Paired t; p < 0.0001
Porto et. al, 2022 [21]	250 mL energy drink (≈32 mg caffeine, 400 mg taurine, glucuronolactone, sugars) consumed 15 min before moderate aerobic exercise; placebo = 250 mL water. Measurements during rest, exercise, and recovery.	n = 28 young adult males	Randomized, double-blind, placebo-controlled, crossover trial	Repeated-measures comparisons between energy drink vs placebo conditions; time-effect testing; ANOVA/within-subject comparisons for HR, SBP, DBP, HRV indices (software not clearly specified).	No significant change of BP and HR after consumption of ED.
Akhundova et.al, 2021 [22]	Consumption of a single 355 mL can of an energy drink containing 53.25 mg of caffeine.	30 healthy volunteers (15 men, 15 women), age range 19-46 years.	Pre-post (within-subject) single group open-label study of healthy volunteers; baseline measurements, drink, then repeat at 60 minutes.	The Statistical Package for the Social Sciences version 15 software (IBM Corporation Armonk, New York, USA) package was used to evaluate the data obtained in the study.	Heart rate: 72.6 ± 9.5 bpm (baseline) to 70.4 ± 9.7 bpm (60 min) (p = 0.056). Systolic BP: 111 ± 11.4 mmHg to 114 ± 12.9 mmHg (p = 0.592).Diastolic BP: 72.3 ± 7.9 mmHg to 73 ± 8.0

				Sample t-test and Wilcoxon signed ranks used to compare baseline and post-consumption	mmHg (p = 0.714).
Mandilaras et al., 2021 [23]	ED dosage was bodyweight-adjusted (3 mg caffeine per kilogram of bodyweight) and reflected the maximum daily caffeine intake for healthy children and adolescents as proposed by ESFA. Participants were given either commercially available caffeinated ED or placebo drink without ED components on 2 consecutive days.	26 children and adolescents (mean age 14.49 years).	Randomized, double-blind, placebo-controlled, crossover study design.	Two-way repeated-measures ANOVA, evaluating the mean HR, QTc and QT-RR relationship over time of the beverages.	Mean HR in ED group was lower (p = 0.001) than placebo group during the time period of 60-120 min post-consumption. No significant differences in the remaining time periods. No statistically significant effect on QTc for both groups (p= 0.05).Median QT-RR in ED group was lower than placebo group (p < 0.01; median difference = 0.062).
Oberhoffer et al., 2023 [24]	Study participants received asingle, bodyweight-adjusted ED amount or a placebo drink on 2 consecutive days at similar morning hours.	17 healthy children andadolescents aged 10–18 years.	Randomized, single-blind (study participants), placebo-controlled,crossover clinical trial.	the Shapiro–Wilk test, histograms, and QQ plots, paired t-test, Wilcoxon signed-rank test, SPSS	Bodyweight-adjusted ED dosage is linked with a significantlyhigher median 24-h SBP (+5.26 mmHg) and DBP (+3.45 mmHg),compared to a placebo beverage, in healthy children andadolescents.
Setiabudi, 2024 [25]	Group A received ExtraJoss, while Group B received KratingdaengInitially, afterward, the given drinks were switched	38medical students from UniversitasAirlangga in Surabaya, aged between 19and 22 years, with a normal BMI range of 18.5-24.9	Open trial – randomized cross-over study method.	Wilcoxon and Mann-Whitney tests, SPSS software (IBM SPSSStatistics) version 26.	Consumption of Extra Joss and Kratingdaeng increased systolic and diastolic values, while pulse rate remained unchanged.
Nwachukwu et al., 2024 [26]	Divided into (3) three different groups (A, B, C). Group A, which constitute of 20 young adult (10 female, 10 male) were subjected to consume 250ml of energy drink and experiment was carried out	25 male and 25 female subjects aged 21-25 years, weighing 52-92 kg	Experimental, controlled, parallel	Calculated mean and standard deviation, T-test, paired T-test using SPSS version 25.	Heart rate, diastolic and systolic blood pressure increased.

	for 2hrs post consumption. Group B, which constitute of 20 young adult (10 female, 10 male) were subjected to consume 500ml of energy drink and experiment was carried out for 2hrs post consumption. Group C, which is the control group constitute of 10 young adult (5 female, 5 male) were subjected to consume 500ml of drinking water.				
Mahmood et. al, 2024 [27]	divided into three categories: no drink at all, occasionally (<1/day) and frequently (one and more/day).	438 healthy students, age range 18-25 years.	Cross-sectional study.	GraphPad Prism version 5 (GraphPad Software Inc., United States) and IBM SPSS Statistics for Windows version 26 (IBM Corp., Armonk, United States), T-test	ED drinkers had significantly higher rates of elevated blood pressure (56.4%, n=173), palpitations (63.1%, n=194), and chest discomfort (73.2%, n=225) compared to non-drinkers ($p < 0.0001$)
Chen, n.d. [28]	Each participant consumed 2 16-oz cans of a commercially available ED daily, divided into 2 doses, for 28 days.	Of the 14 participants enrolled in the study, 12 completed the full study protocol for 28 days.	Unblinded, non-randomized, proof-of-concept, prospective study.	Wilcoxon signed-rank test, Microsoft Excel for descriptive statistics (Version 16.10, Microsoft, Redmond, WA), SPSS for all other statistics (Version 26, IBM Corporation, Armonk, New York)	Daily consumption of 2 cans of ED/day for 28 days significantly increases blood pressure and heart rate, as well as QTc interval and fasting blood glucose.
Bashir et. al, 2018 [29]	Each day, heart rates and blood pressures of 3 to 4 students were measured and then the tests of physical performance (hand grip test and 300 meter run test) were performed ("pre-test" measurements). After that, each student drank 250 mL	Sixty-eight medical students participated in this study.	Experimental study.	SPSS version 17.0 (IBM Corporation, USA), T-test.	The cardiac parameters (heart rate & blood pressure) of the students increased significantly after using the energy drink (p-value < 0.05). Mean±SD hand grip of the students increased from 44.97±3.96 Kg to 45.14±3.99 Kg after consuming the energy

	of a standard energy drink and then rested for about 30 minutes, after which post-test measurements were recorded in the same way				drink, but this increase was not significant (p-value = 0.667).
Nowak et. al, 2019 [30]	Divided into 4 groups, which consumed three portions of noni or chokeberry juices (30 mL or 200 mL, respectively) and ED or water (200 mL) at one-hour intervals.	88 healthy volunteers, average age 25 years (49 females, 39 males).	Randomized Controlled Trial, parallel group design.	Mean, standard deviation, MS Excel 2010 Analysis ToolPak software (Microsoft, Redmond, WA, USA), with one-way analysis of variance (ANOVA) and Tukey's test as the post hoc test; p values lower than 0.05 were considered as significant.	SBP (5.0%) and DBP (7.5%) of noni juice consumption decreased.DBP (3.6%) of chokeberry consumption was slightly decreased. Consumption of ED increased in DBP by 14.7%.BG of noni juice consumption decreased (7.3%), while BG of consumption of ED increased (15.8%).
Tan et. al, 2019 [31]	Ingested 6 mg per kg of body mass of (a) caffeine or (b) maltodextrin (placebo) on two separate occasions in a random order. After 60 min, they performed five sets of a match-simulated basketball protocol comprising six sideline-to-sideline sprints on a standard basketball court, followed by two free throws after each set.	12 males and 6 females basketball players	Single-blind, placebo-controlled, randomized design.	SPSS 25.0 software (IBM Corp, Armonk, N.Y., USA), Shapiro-Wilk test, T-test, ANOVA.	Caffeine increased heart rate (p = 0.02) but did not affect RPE (p = 0.57) across five sets compared with placebo.
Chtourou et al., 2019 [32]	Two sessions: after drinking the "Red Bull" beverage and after drinking a placebo. Two test sessions were separated by an interval of seven days.	19 male physical-education students.	Randomized double-blind, placebo-controlled, counterbalanced, crossover design.	"Statistical Package for Social Sciences" SPSS v21.0 software(SPSS Inc., Chicago, IL) and Microsoft Excel 2010 (Microsoft Corp., Redmont, WA, USA), Shapiro-Wilk's test, T-test, ANOVA.	Cognitive and short-term maximal performances improved after Red Bull ingestion.Further ingestion of Red Bull increased pre- and post-exercise blood glucose and blood pressure.

Caliskan, 2024 [33]	Divided into four main groups: caffeine, taurine, caffeine + taurine, and a control.	56 students from Aydın Adnan Menderes University.	Single-blind, randomized study.		SPSS Statistics for Windows,Version 22.0 (SPSS Inc., Chicago, IL, USA), Shapiro-Wilk normality test, Bonferroni post-test.	For caffeine and caffeine + taurine groups, HR and SBP increased, while in taurine group no significant difference.An increase in HR and SBP at 60 min for caffeine group was significant compared to control group ($p = 0.012$,$p = 0.035$, respectively). No difference in taurine group.For, DBP for caffeine, caffeine + taurine, taurine did not change over time also no alterations were observed in control group.

Discussion

The focus of this review is to evaluate the impact of energy drinks on systolic blood pressure (SBP), diastolic blood pressure (DBP), and heart rate (HR) from various existing studies which involve adolescents and adults. Overall, it can be observed that the findings and outcomes show a clear pattern, which is consumption of energy drinks can cause acute stimulation on cardiovascular parameters that can be analysed by the increase of the blood pressure, systolic and diastolic, and also heart rate. However, the strength and consistency of the results differ from study to study.

In the considered clinical studies, SBP shows the most consistent and significant increase after the intake of ED. Several randomised and crossover studies before that reported major increases which are generally ranging from 4-11 mmHg, occurring within 30 to 90 minutes post-consumption. The examples include the studies by Shah et al. [1], Basrai et al. [2], Kozik et al. [3], and Bendary et al. [4], all of which noted statistically significant elevation of SBP. As well as in paediatric trials, including those conducted by Oberhoffer et al. [5] and Mandilaras et al. [6], also revealed a significant increase in blood pressure when applying weight-adjusting ED dosage. On the other hand, a few studies, especially those with reduced caffeine levels, like Akhundova et al. [7] and Costa et al. [8], found no significant changes in SBP, suggesting that caffeine concentration may be a critical factor that can influence the systolic readings of the participants.

Recent studies have further supported this pattern. Banks et al. [9] noted that both calorie-free and sugar-containing ED can raise resting SBP significantly ($p < 0.001$), and that this effect is even stronger after the graded activity testing. Similarly, Park et al. [10] discovered that both central and peripheral SBP significantly increased following the consumption of Monster energy drinks observed both in sedentary and moderately active people, thus confirming that ED-related SBP increases appear across varying levels of physical activity. Besides, Schüttler et al. [11] also found that both peripheral and central SBP increase a lot after consumption of ED that contain 240 mg caffeine, which proves that the effects can depend on the dose taken by the participants.

Conversely, diastolic BP shows greater variability from study to study. Several investigations, including those conducted by Kozik et al. [3], Basrai et al. [2], Nwachukwu et al. [12], and Bendary et al. [4], indicated a noticeable increase in DBP. On the other hand, studies conducted by Nowak et al. [13] and Costa et al. [8] have observed no significant changes. Moreover, a gender-specific pattern also appeared. This is supported in the studies of Rabuya et al. [14] that discovered a significant increase in DBP in male athletes, although no such changes were observed in female athletes. This important finding indicated that sex hormones, autonomic tone, or baseline cardiovascular fitness can affect the haemodynamic responses. Furthermore, the increase in DBP was also more obvious in studies with higher stimulant content, using multiple servings of ED, or prolonged post-consumption testing intervals. Thus, it can be interpreted that this variability can influence DBP and it may have higher sensitivity to both dosage and individual physiological characteristics when compared to SBP. Park et al. [10] also observed rises in DBP in both sedentary and physically active groups; however, the bodybuilding group did not show any significant and similar responses. This is perhaps because they have more flexible arteries adapted to training.

Next, the effects of EDs on heart rate were also different and not consistent across various studies. Some of the tests, such as those conducted by Patil et al. [15], Nwachukwu et al. [12], Bendary et al. [4], Kozik, et al. [3] and Basrai et al. [2] have indicated a substantial increase in heart rate after the use of energy drinks. This result is consistent and aligned with the chronotropic effects of caffeine that can enhance the sympathetic nervous system and catecholamine release, which will then result in increased heart rate [16]. However, several studies also reported that there is no significant increase or decrease that can be observed from heart rate values after post-consumption of energy drinks; this includes the studies managed by Lee [17], Nowak et al. [13], and Higgins et al. [18]. Interestingly, one paediatric randomized trial [6] reported a reduction in HR observed during particular post-

consumption intervals. Hence, this rare finding may be due to the amount of taurine used in the study, since taurine has been proven to have negative chronotropic effects, which potentially could counteract the effects of caffeine [16]. Next, the studies by Banks et al. [9] found that both types of ED significantly increase HR ($p = 0.010 - 0.035$), whereas Tan et al. [19] observed a rise in HR after basketball-specific exercise following the ingestion of caffeine. Chtourou et al. [20] also found that drinking Red Bull before and after exercise raised blood pressure and metabolic reactions. This supports the hypothesis that EDs may make the heart work harder during physical activity.

Furthermore, there are a number of physiological mechanisms that could explain the cardiovascular response that have been observed and reported across the studies. For instance, the main stimulant in EDs, which is caffeine, is an adenosine receptor antagonist that stimulates the release of catecholamine. This hence led to the vasoconstriction of peripheral blood vessels, a higher cardiac output, and enhanced sympathetic activation [6]. In addition, a lot of sugar content in EDs may also be one of the factors since it raises blood sugar levels and stimulates additional sympathetic activity [2]. Other than that, ingredients such as guarana and taurine are two major components that can change the calcium flow to heart tissue and either produce higher or lower ED symptoms, depending on the dose and how they interact with other ingredients [2,6]. Studies involving physical activity, such as conducted by Kozik et al. [3], show an increase in blood pressure and heart rate response, which is likely caused by continuous sympathetic activation throughout exercise.

Age also seems to influence the effects of EDs on cardiovascular outcomes. In some studies, as reported by Oberhoffer et al. [5,21] and Mandilaras et al. [6], they noted that children and teens had larger BP effects compared to adults. This is because younger people may have higher plasma caffeine levels after the same ED serving due to lower body mass and different caffeine metabolism. Long-term cardiovascular changes may also be caused by chronic consumption of ED. Mahmood et al. [22] and Menzel et al. [23] both reported that people who used ED regularly were more likely to have high blood pressure or other cardiovascular symptoms, suggesting a build-up of effects over time.

Finally, the differences in analytical tools used in different studies may also be a contributing factor that influences the variability in the findings of cardiovascular parameters after the consumption of ED. Some research applied more sensitive statistical methodologies such as repeated-measures ANOVA or mixed-effects models like Banks et al. [9], which are better at detecting small changes over time. In contrast, there are some studies that utilised more straightforward methods like pre-post comparison or non-parametric procedures, this includes the Wilcoxon signed-rank test such as conducted by Schüttler et al. [11], which might exhibit less sensitivity in small samples. Additionally, strict correction methods for multiple comparisons, for instance, the Holm-Sidak and Bonferroni methods, may reduce the probability of identifying the significant changes that occur. Thus, these methodological differences affect the detection of minor changes in BP or HR, leading to the variation reported in the literature. Other than that, variability in findings can also be explained by the differences in caffeine dose, ED formulations, timing measurements, study methodology, fitness level, and regular caffeine intake. Even with these differences and variations, the overall evidence strongly suggests that energy drinks increase the SBP and frequently DBP and HR.

All in all, these findings have important implications for public health given the popularity of EDs among adolescents, athletes, and young adults. This is because even small yet repeated increases in BP and HR can contribute to the risk of cardiovascular disease over a long period. Therefore, ongoing research and studies, especially long-term and exercise-based studies, are crucial to fully understand the chronic effects of ED consumption, and to raise awareness about the potential negative consequences associated with EDs.

Conclusion

This systematic review showed that a significant increase in SBP occurs during post-consumption within 30-90 minutes, which is the most coherent result in most previous studies. The correlation between the dose of caffeine intake and higher SBP readings in post-consumption showed a positive outcome, with the effect being even stronger after the graded activity testing. In contrast with DBP readings, studies reported varied results and it can be concluded that the DBP readings may be influenced by gender-specific patterns, sex hormones, autonomic tone or baseline cardiovascular fitness. Besides, the concentration of stimulant contents in EDs or prolonged post-consumption testing intervals may also affect the DBP readings. Additionally, the heart rate readings in most studies also exhibit inconsistent results. In most studies, caffeine intake increases heart rate readings, which aligns with the chronotropic effect of caffeine in elevating the sympathetic nervous system and catecholamine release. However, in some studies, the results are against it. On the other hand, the consumption of ED content such as taurine reduced the heart rate readings, which corresponds with the proven study of taurine having negative chronotropic effects. To be added, the data that are analysed using repeated-measures ANOVA and mixed-effects model have higher reliability as it more sensitive to small readings compared to pre-post comparison and non-parametric procedures. The cardiovascular parameters are influenced by many types of possible rationales depending on the study designs used, the study population characteristics, dietary, lifestyle, statistical analysis methods used and other inferences that are closely related to the collected parameter readings.

Conflict of interest

The authors declare no conflict of interest.

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